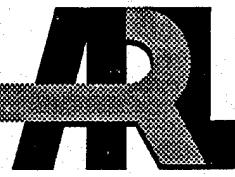


ARMY RESEARCH LABORATORY



Fort Drum Ballistic Barrier Tests

William S. de Rosset
Eleanor C. Deal

ARL-TN-65

March 1996

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13. ABSTRACT (Maximum 200 words) Experiments were conducted to determine the response of a laminated target to small arms fire. The target represented the ceiling used to separate the floors of a two-story building in a live fire village at Fort Drum, New York. The target consisted of 3/4-in plywood, a steel plate, a second piece of 3/4-in plywood, a second steel plate, and a third piece of 3/4-in plywood. The tests were conducted to establish whether this target would protect troops in the building against the accidental discharge of small arms weapons being fired from one floor to the other. The tests showed that use of 1/4-in mild steel in the laminate will stop 5.56-mm ammunition, and that 1/2-in steel will stop 7.62-mm ammunition.			
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1. INTRODUCTION

In response to a request from personnel at Fort Drum, New York, the U.S. Army Research Laboratory (ARL) undertook a series of ballistic tests to determine the stopping power of a wood-steel laminate when fired upon by small arms ammunition. The laminate was being used as a divider between floors of a two-story building located in a live fire village. The purpose of the tests was to determine whether troops located on the downrange side of the divider were safe in the event of an accidental discharge of a weapon. The Corps of Engineers questioned whether the proposed design would be sufficient to stop small arms ammunition, which necessitated actual firings.

Within one week of the original tasking, ARL had acquired the target material, assembled the targets, obtained the necessary weapons and ammunition, conducted the tests, analyzed the results, and provided preliminary results (verbally) to Fort Drum. This quick response was necessary to provide critical information for contract specifications. After the preliminary results were reported, ARL was informed that a change had been made in the design of the target to assure that a higher degree of safety was achieved. The second design was also examined in ballistic tests. The next section describes the original target and the modification made to it. This section also contains the experimental procedure used. Section 3 contains the experimental results, which are discussed in Section 4. The final section presents the conclusions drawn from the tests.

2. EXPERIMENTAL PROCEDURES

2.1 Target Description. The original target was specified as 3/4-in plywood, 1/4-in steel, 3/4-in plywood, 1/4-in steel, and 3/4-in plywood. The steel was specified as A572 Grade 50, which is a high-strength, low-alloy steel used in construction when high strength is needed. The specified minimum tensile strength for this steel is 65 ksi (see Manual of Steel Construction, 7th edition, published by the American Institute of Steel Construction, New York, NY, 1973). This type of steel was not available on short notice, so another steel was substituted for it. The Brinnell hardness for the substitute steel was measured to be around 125; while an exact conversion between Brinell Hardness (BHN) and tensile strength is not possible, an approximate conversion shows that BHN 125 corresponds to a range of tensile strength between 60 and 65 ksi (Small, 1960). In any event, use of a lower strength steel in these tests provides a conservative estimate of the stopping power of the laminate target.

The modification made to this target by Fort Drum was to replace the 1/4-in steel with 1/2-in steel. The Brinell Hardness of the 1/2-in steel used in these tests was approximately BHN 130. In subsequent discussions, this will be referred to as the modified target.

All targets had lateral dimensions of 12 in by 12 in (305 mm by 305 mm).

2.2 Weapon and Ammunition. For the majority of the tests, 5.56-mm M855 ball ammunition was used. The lot number of the ammunition was WCC85L030-039. A schematic of the bullet is shown in Figure 1 (taken from TM 43-0001-27). The cartridge is identified by a green tip and is used against personnel and unarmored targets. The nominal velocity is 3025 ft/s (922 m/s) at 78 ft from the muzzle. This is standard ammunition for the M16A2 rifle.

The last group of tests performed used 7.62-mm M80 ball ammunition. The lot number of the ammunition was LC86K601L198. A schematic of the bullet is shown in Figure 2 (taken from TM 43-0001-27). Its nominal velocity is 2750 ft/s (838 m/s) at 78 ft from the muzzle. This ammunition is used in the M14 rifle.

2.3 Test Procedures. All tests were conducted in Range 110, located in Building 309 at Aberdeen Proving Ground. Five groups of tests were performed; these are summarized in Table 1. Standard multiple-flash x-ray techniques were used to measure projectile impact velocity, yaw, and pitch (Herr and Grabarek 1966). The sign convention for pitch and yaw is shown in Figure 3. In all cases, the gun-to-target distance was 4 ft. A picture of the target setup is shown in Figure 4. The five target layers are shown here clamped at each corner with a c-clamp.

The purpose of the first group of tests was to determine the resistance of the original target to the M855 bullet. The next group of tests examined a worst-case scenario in which the impacts occurred sequentially at the same spot on the target. The third group of tests was used to determine at what target obliquity ricochet would begin to occur. Firings began at 10° obliquity and increased in 10° increments until an obliquity of 60° was obtained. (Obliquity here is defined as the angle between the bullet trajectory and the normal to the target (see Figure 5)). The fourth and fifth group of tests examined the resistance of the modified target to impact of M855 and M80 ammunition, respectively.

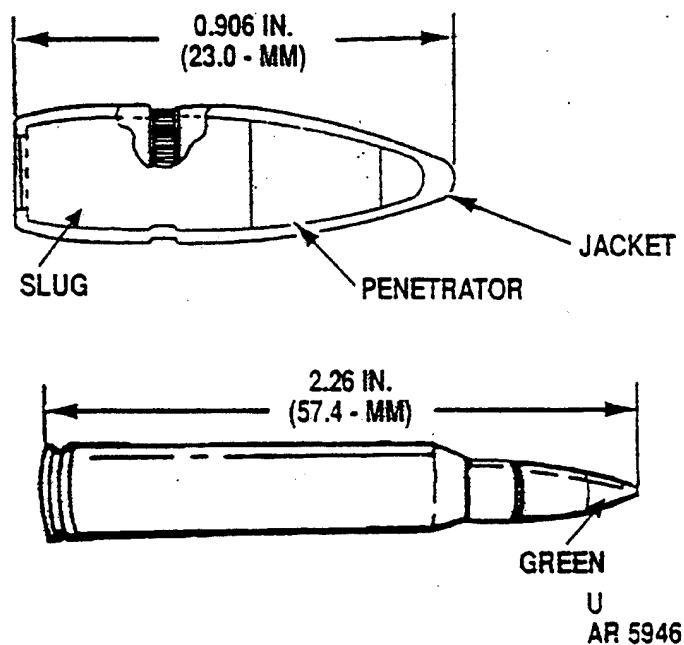


Figure 1. Schematic of M855 cartridge.

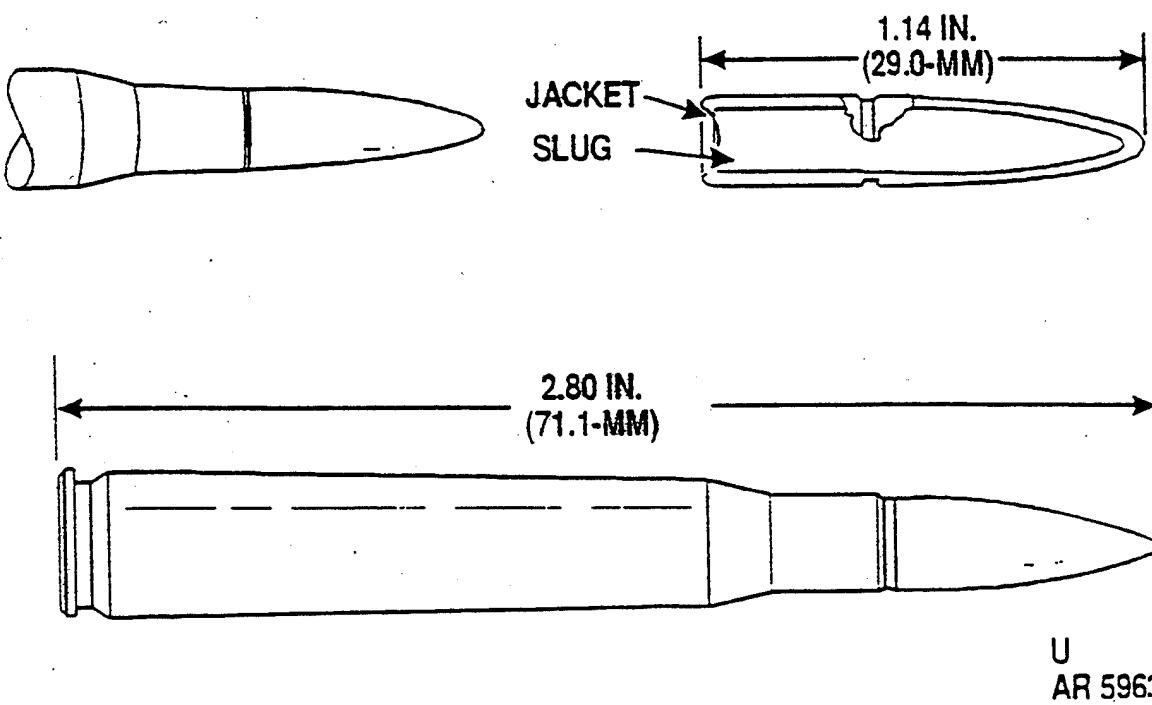


Figure 2. Schematic of M80 cartridge.

Table 1. Test Group Summary

Group No.	Bullet Type	Number Tests	Target Type	Target Obliquity (°)	X-ray Coverage (No. Tests)	Test Type
1	M855	5	original	0	5	target qualification
2	M855	3	original	0	0	multiple impact
3	M855	6	original	10-60	6	obliquity tests
4	M855	5	modified	0	1	target qualification
5	M80	5	modified	0	2	target qualification

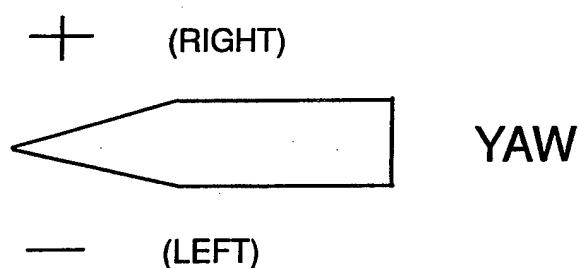
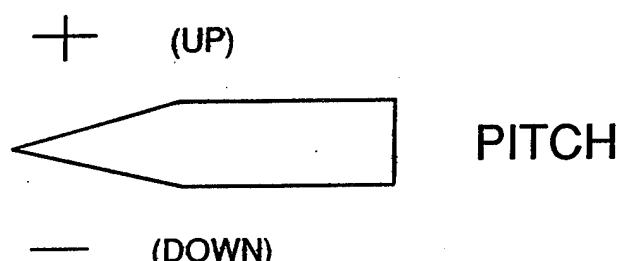


Figure 3. Pitch and yaw sign conventions.

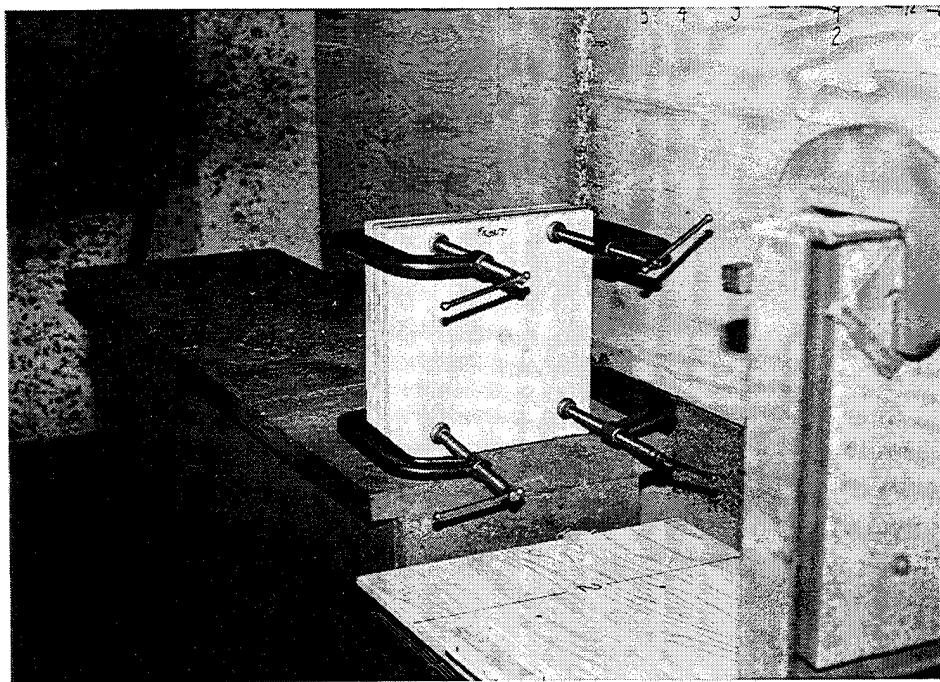


Figure 4. Target setup.

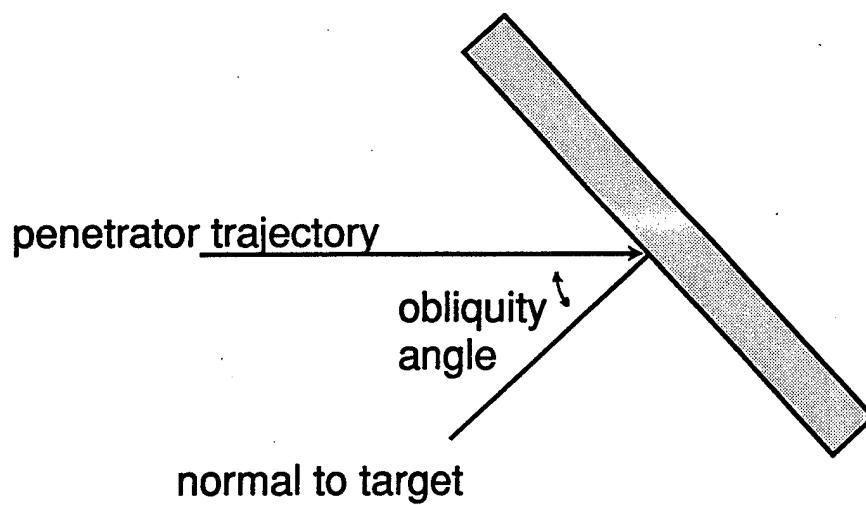


Figure 5. Definition of obliquity angle.

3. RESULTS

The results for the first group of firings is shown in Table 2. In all these tests, the bullet went through the first three layers of the target and lodged in the fourth layer. Table 1 shows the impact velocity, pitch, yaw, and the depth of penetration into the fourth layer (1/4-in steel). A depth measurement could be made in all but the fourth test. In this case, the core of the M855 lodged in the steel plate. The bulge height represents the maximum deflection from the rear surface of the steel plate. The notation "NM" in Tables 2, 4, and 5 indicates a measurement was not taken.

Table 2. Group 1 Test Results

Test Number	Velocity (m/s)	Pitch (°)	Yaw (°)	Penetration Depth Into 2nd Steel Plate (mm)	Bulge Height on 2nd Steel Plate (mm)
1	908	+5.5	-3.25	3	1
2	900	+2.5	-0.75	4	1
3	913	+4.0	-1.75	3	1
4	915	-0.25	-3.75	penetrator lodged in plate	3
5	NM	NM	NM	4.5	2

The result from the second group of tests (test numbers 6 though 8) was that it took three separate firings at the same spot on the target to achieve a complete perforation of all the layers.

The results from the third group of firings are shown in Table 3. At 10°, the results are not much different from those obtained at 0°. In the test at 20° obliquity, the bullet core lodged in the second steel plate and an accurate measurement of the penetration depth was not made. At 30°, the bullet is still getting through the first steel plate and causing some damage to the second steel plate. However, the penetration depth is now only 3 mm and the bulge height has decreased to 1 mm. At 40° obliquity, there is only a trace indentation on the surface of the second steel plate, and no bulge height could be measured. At 50° obliquity, the bullet was unable to perforate the first steel plate. It did make a deep scoop in the first plate, and there was a small hole in the plate at the tip of the bulge. The damage to this steel

Table 3. Group 3 Test Results

Test Number	Velocity (m/s)	Pitch (°)	Yaw (°)	Target Obliquity (°)	Penetration Depth Into 2nd Steel Plate (mm)	Bulge Height on 2nd Steel Plate (mm)
9	917	-0.25	-0.5	10	4	2
10	908	-1.5	+1.75	20	penetrator lodged in hole	2
11	918	-2.25	-3.25	30	3	1
12	893	-0.25	-2.25	40	0.5	-
13	920	+2.5	+0.25	50	ricochet from 1st plate	-
14	907	+3.25	-0.75	60	ricochet from 1st plate	-

plate indicates that ricochet has been initiated. A small chunk of metal exited the front face of the target. This was most likely the bullet core, although it could also have been a small piece of the first steel plate. Figure 6a shows the front of the first plywood sheet; note the small entrance hole and large exit hole beneath it. Figure 6b shows the back of the first steel plate. There is a small hole located at the tip of the bulge. The test at 60° obliquity was similar to the test at 50° obliquity. However, in this case a much larger piece of metal exited the front of the target, causing a much larger hole in the plywood cover.

The results for the fourth group of tests are shown in Table 4. Since this was essentially a repeat of the first group with a different target, only one velocity measurement was made. In four of the five tests, the bullet was stopped in the first steel plate (1/2-in steel). Since the bullet was found to be lodged in the first steel plate in these tests, no recording was made of the penetration depth. In test 17, the penetrator was found lodged in the 3/4-in plywood behind the first steel plate. There was no damage done to the second steel plate in this case.

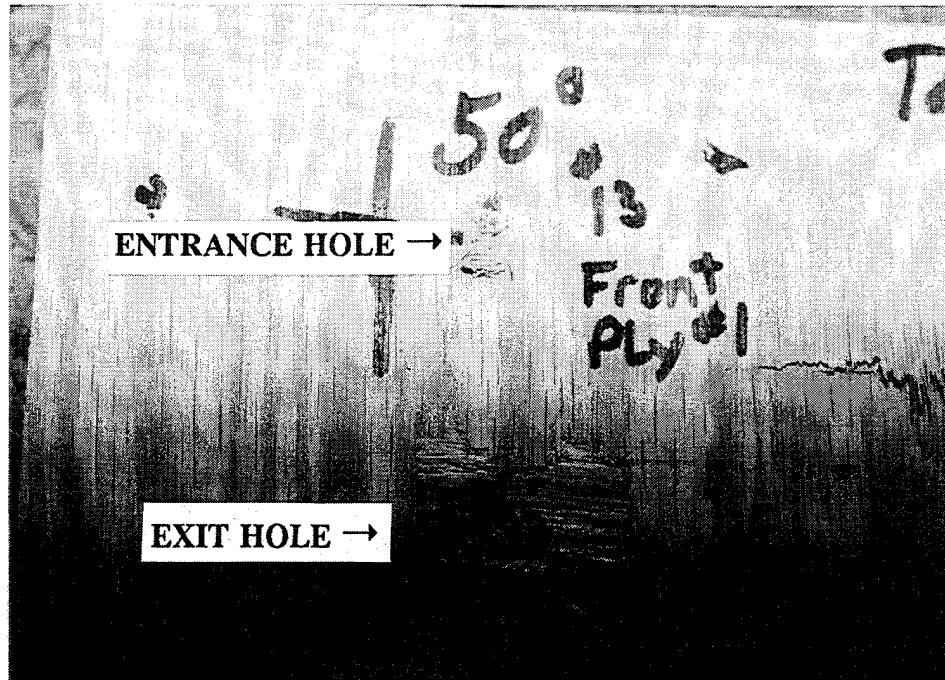


Figure 6a. Front of first plywood sheet, test 13.



Figure 6b. Rear of first steel plate, test 13.

Table 4. Group 4 Test Results

Test Number	Velocity (m/s)	Pitch (°)	Yaw (°)	Bulge Height in 1st Steel Plate (mm)
15	907	-1.25	+0.5	3
16	NM	NM	NM	2.5
17	NM	NM	NM	complete penetration of first steel plate
18	NM	NM	NM	3
19	NM	NM	NM	3

Table 5 gives the results of the last group fired. No perforations of the first steel plate were achieved with the M80. X-ray coverage was provided for two tests (21 and 22). As before, the penetrator lodged in the first steel plate, and a measurement of the penetration depth was not made. The large bulge in the first steel plate caused a noticeable depression in the 3/4-in plywood backing up this plate. There was no mark on the second steel plate.

Table 5. Group 5 Test Results

Test Number	Velocity (m/s)	Pitch (°)	Yaw (°)	Bulge Height in 1st Steel Plate (mm)
20	NM	NM	NM	8
21	854	+0.25	+3.25	9
22	847	+1.25	-0.25	8.5
23	NM	NM	NM	8
24	NM	NM	NM	8

4. DISCUSSION

The tests in Group 1 show that the original design provides adequate protection against M855 ball ammunition. In none of the tests conducted did the bullet perforate the target, and the penetration depth into the second steel plate was on the order of half the plate thickness. The consistency of the results

suggests that excursions from the observed performance would be unlikely. Use of higher strength steel in this design would improve the margin of safety. Note that firing the weapon at a distance longer than the 4 ft used in these experiments will also cause the margin of safety to increase.

Group 2 tests show that a second round fired at the same point on the target will not result in a perforation. It took three separate firings to produce a complete perforation. While this group of tests may not provide a statistically significant number of results, the tests do reinforce the finding that the original design provides an adequate level of protection.

Experiments conducted with the original target at increasingly higher obliquity provided an increase in the path length of steel that the bullet encounters. At some point, the effective target thickness is too great for a perforation of the steel plate, and ricochet occurs. The tests in Group 3 indicate that this critical ricochet angle lies near 50°. Up to that obliquity, the bullet will remain trapped inside the laminate. At higher obliquities, there will be some metal fragment ejected from the front face of the target. This could cause potential injury to troops on the same floor the weapon is being fired.

The test results from Group 4 are consistent with those obtained from Group 1. In both groups, the total amount of steel penetrated was approximately the same, with the one exception where the bullet perforated the first 1/2-in steel plate. Obviously, if the original target could stop the M855, doubling the amount of steel in the target would simply increase the margin of safety.

The M80 ball ammunition caused a significant bulge in the first steel plate of the modified target. The kinetic energy of this round is considerably larger than that of the M855; however, the M80 lacks the steel core found in the M855. Consequently, the M80 may cause more damage to the steel plate than that caused by the M855, but with this particular target the test results indicate that the M80 is no more effective than the M855.

5. SUMMARY

- The laminate target made up of 3/4-in plywood, 1/4-in steel, 3/4-in plywood, 1/4-in steel, and 3/4-in plywood will stop M855 ball ammunition fired from the M16A2 rifle at point blank range at normal obliquity (0°).

- In one test series, three separate shots against the same spot on the target were required to perforate the target at normal obliquity (0°). It would be expected that this number would increase as the target obliquity increased.
- The ricochet angle for the laminate target is approximately 50° . At this obliquity or higher, any personnel on the uprange side of this protective barrier are in danger of being hit with metal fragments.
- A greater margin of safety can be obtained by substituting 1/2-in steel for the 1/4-in steel in the laminate target. The modified target was shown to stop M80 ball ammunition fired from the M14 rifle.

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